mmWave Phased Array Antenna on 5G Applications

Joseph D. S. Deng

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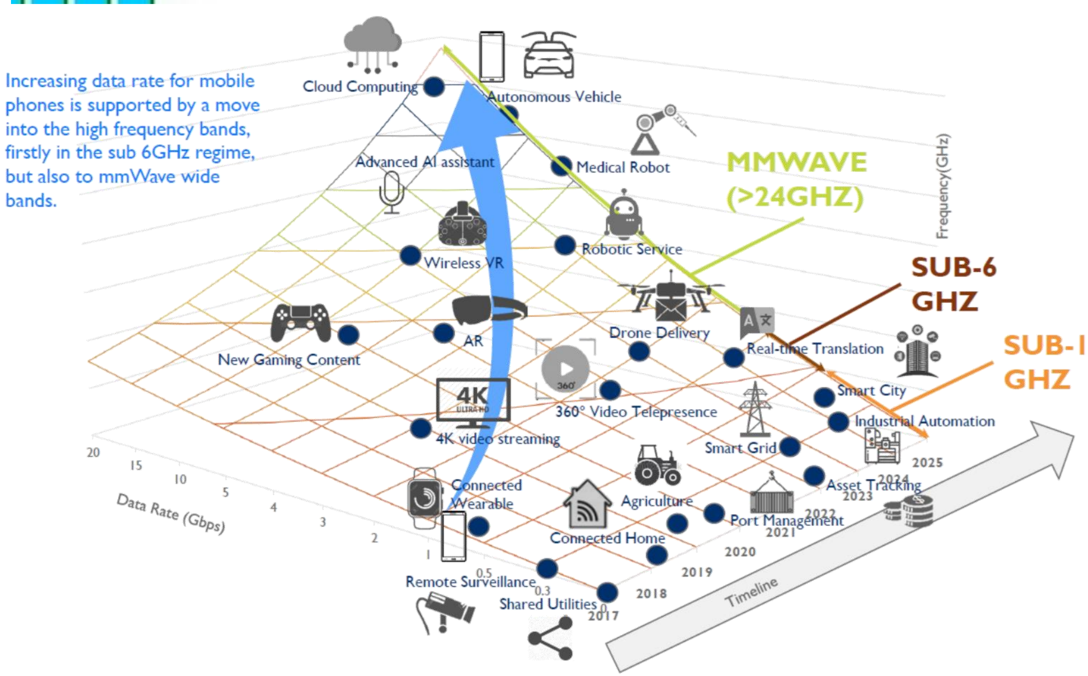
5G Use Cases & Applications

User Experiences (eMBB)

- >10Gbps Peak Rate, 100Mbps Everywhere
- X10K Traffic, 10Mbps/m2 Capacity

- 200MHz/ 400MHz BW is Required
- FR2 mmWave Spectrum Provide Wide Bandwidth



Mission Critical Com+Ctl (URLLC)

- <1msec Latency, 10-5 Outage
- ~0 Mobility Interruption

Everything Connected (mIOT)

- 1M Devices/Km2
- >10Y Battery Life

Cyntec

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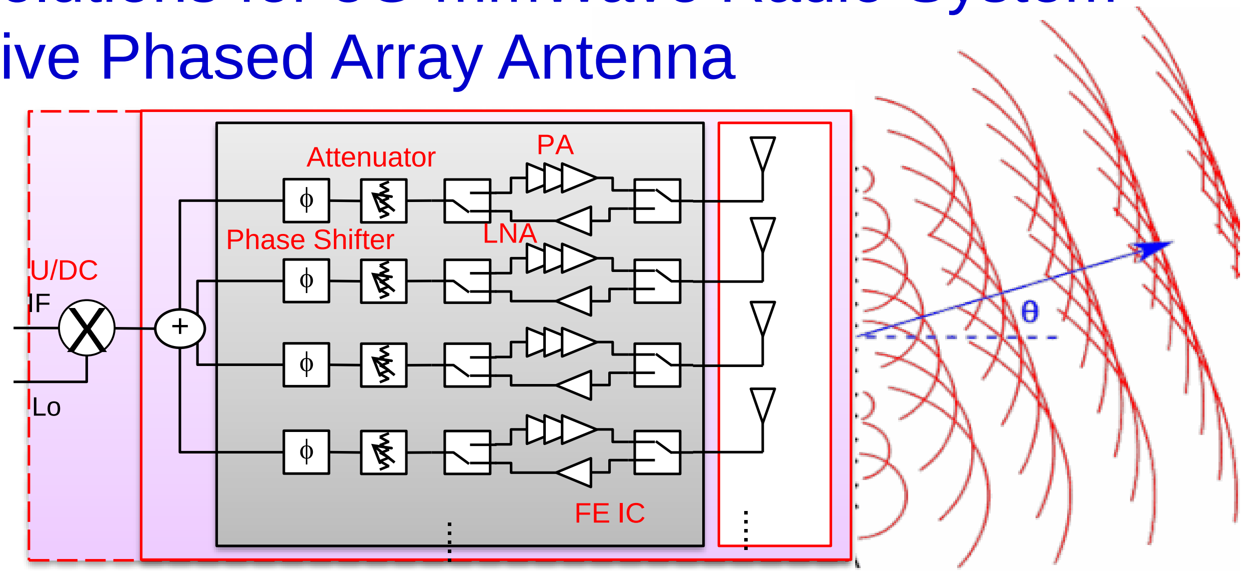
Realities….
-Radiation Wave Characteristics

Wave Length	~10cm	~1cm	~mm
Propagation Characteristics	Wave		Ray
Propagation Loss	Low		High
Circuit Dimensions	Large		Miniature
Semiconductor Capabilities	Good		Poor

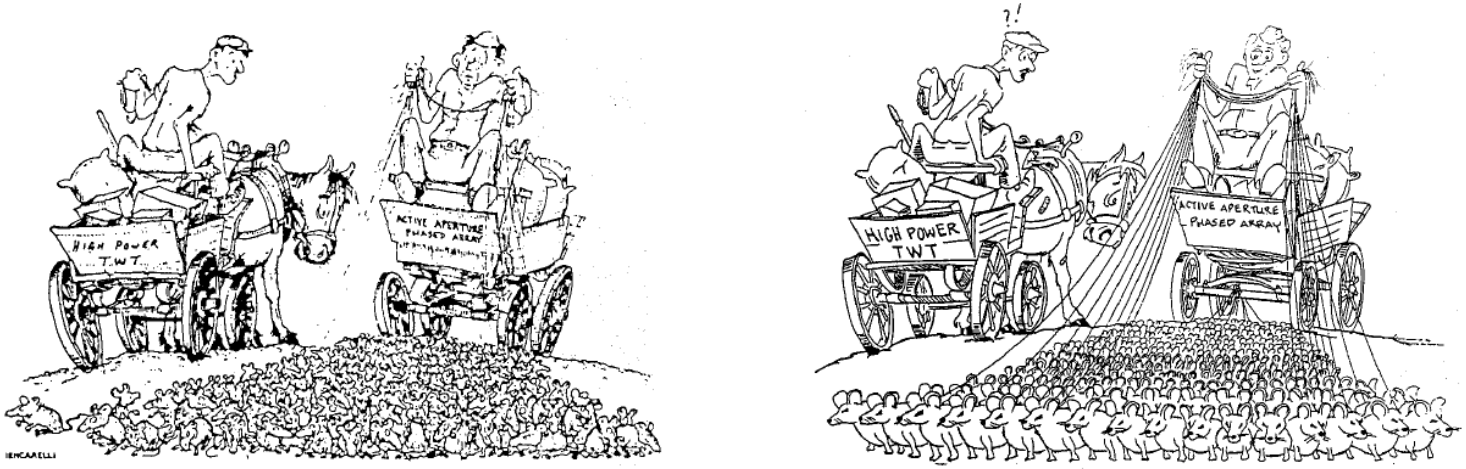
0.6 GHz | 2.5 GHz | 3.4 - 3.8 GHz | 4.4 – 4.9 GHz | ISM | 28 GHz | 39 GHz | . . . | 64 -71 GHz 71 – 76 GHz

Mobile Communication Spectrum

Resolutions for 5G mmWave Radio System -Active Phased Array Antenna



Old Radar Types Never Die, They Just Phased Array…



C. Fowler "Old Radar Types Never Die; They Just Phased Array' or 55 Years of Trying to Avoid Mechanical Scan" IEEE AES Systems Magazine, September

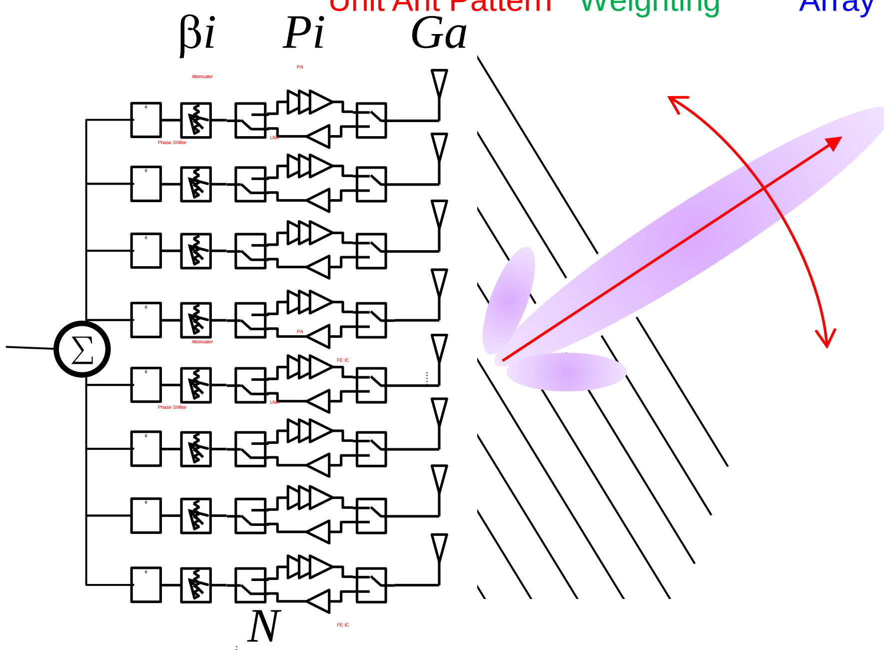
mmWave Communication Resolutions
- Active Phased Array Antenna

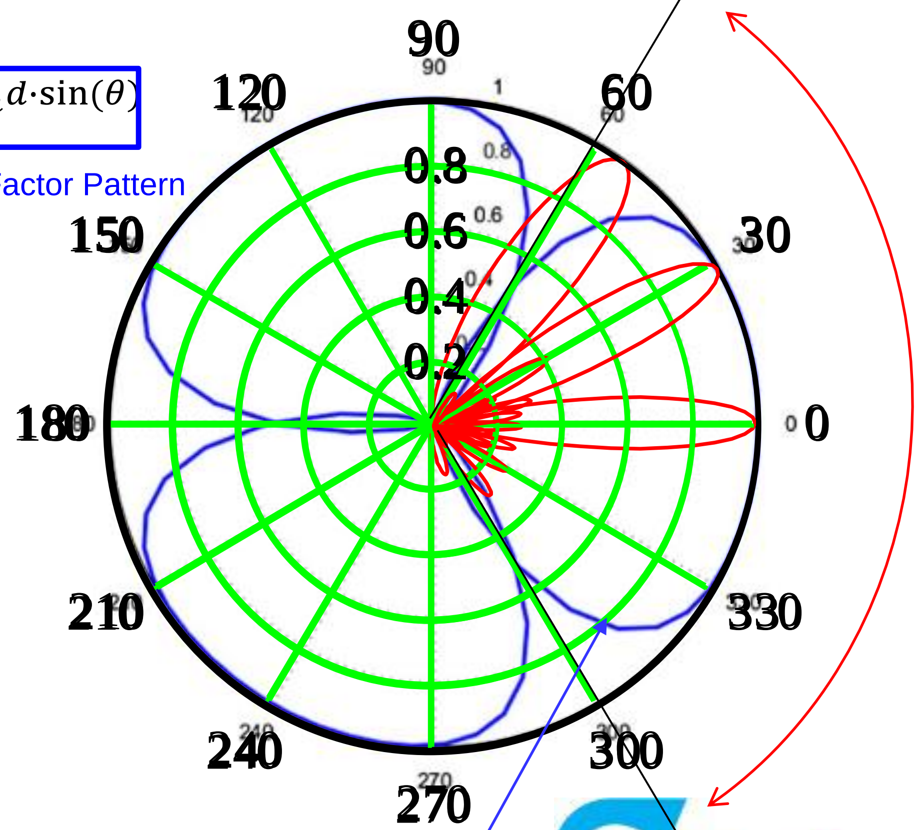
- Beam Forming for Power Spatial Combining
  - EIRP Equivalent Isotropic Power
- Beam Steering for Spatial Coverage

EIRP=$20\log(N) + Pi + Ga - Lf$

Array Pattern=$\sum_{n=0}^{N-1} Ga(\theta) \cdot a_n \cdot e^{j\beta_n} \cdot e^{jk_n d \cdot \sin(\theta)}$

Unit Ant Pattern　Weighting　Array Factor Pattern

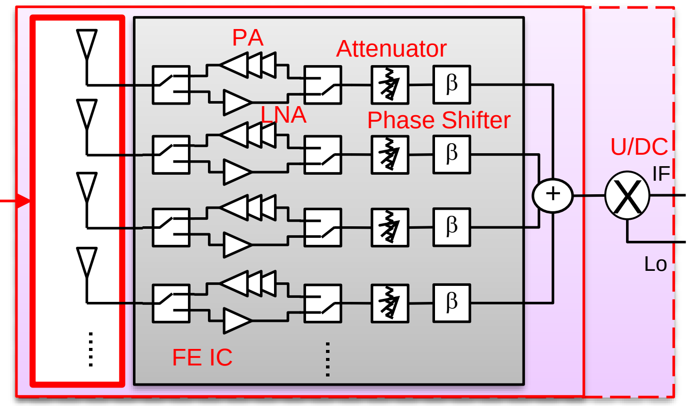




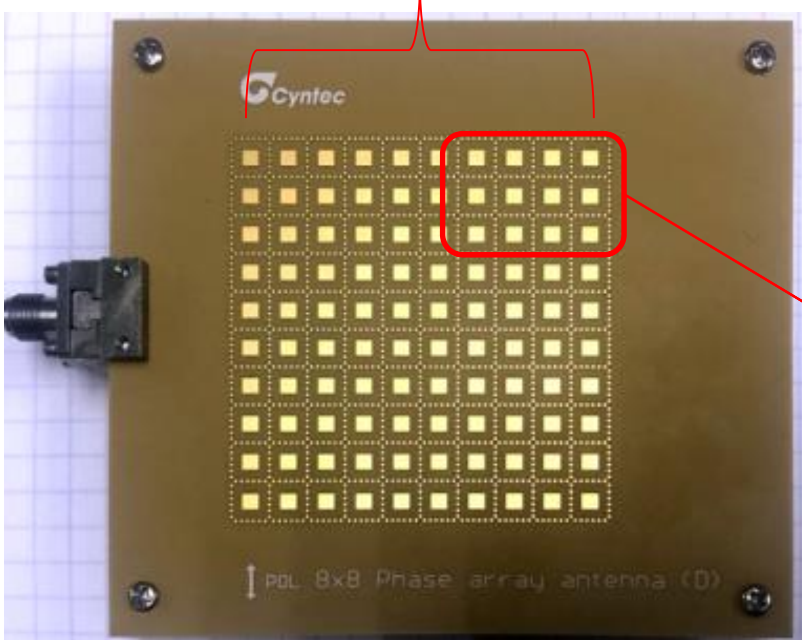
Phased Array Antenna Design Considerations - Array Design

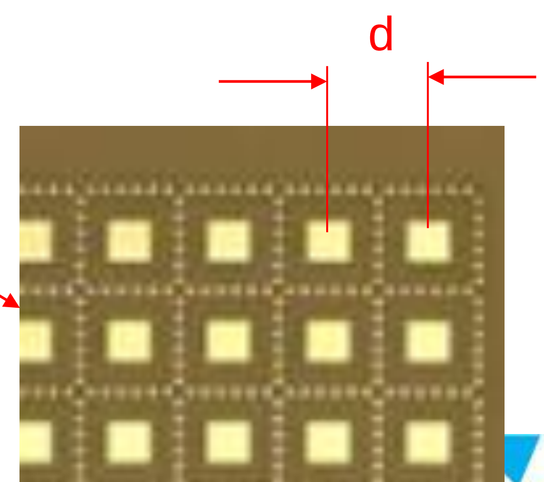
Array Pattern= $\sum_{n=0}^{N-1} Ga(\theta) \cdot a_n \cdot e^{j\beta_n} \cdot e^{jk_n d \cdot \sin(\theta)}$

Unit Ant Pattern | Weighting | Array Factor Pattern



N-Element Array





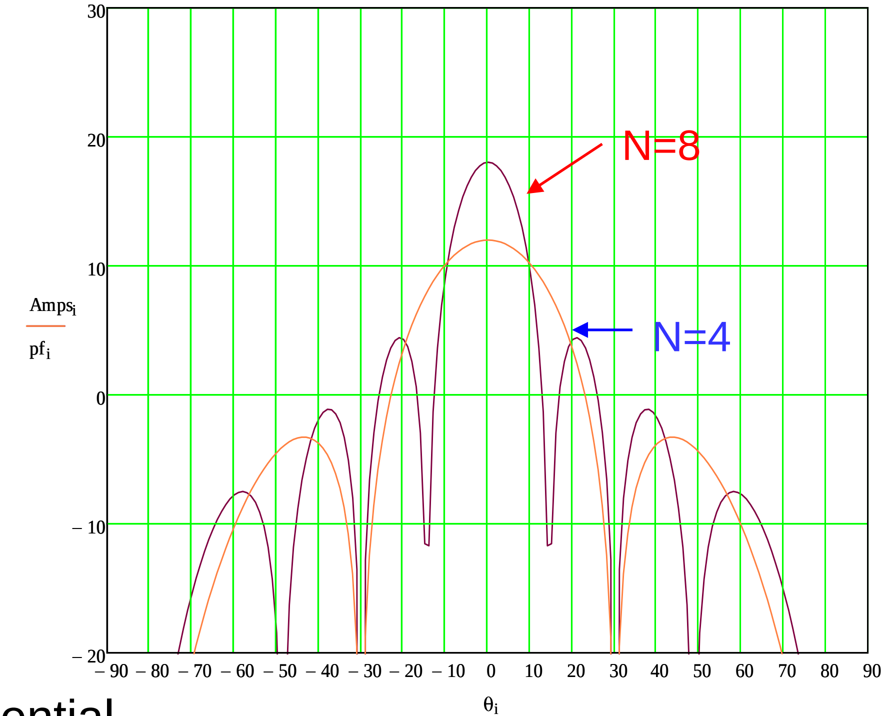
Phased Array Antenna Considerations
- Array Design & Beam Forming Characteristics

More are The Array Elements

- ✓ Higher is the EIRP
- ✓ Higher is the Antenna Gain
- ✓ Sharper is the Beam

$$\text{Array Pattern} = \sum_{n=0}^{N-1} Ga(\theta) \cdot a_n \cdot e^{j\beta_n} \cdot e^{jk_n d \cdot \sin(\theta)}$$

Unit Ant Pattern   Weighting   Array Factor Pattern



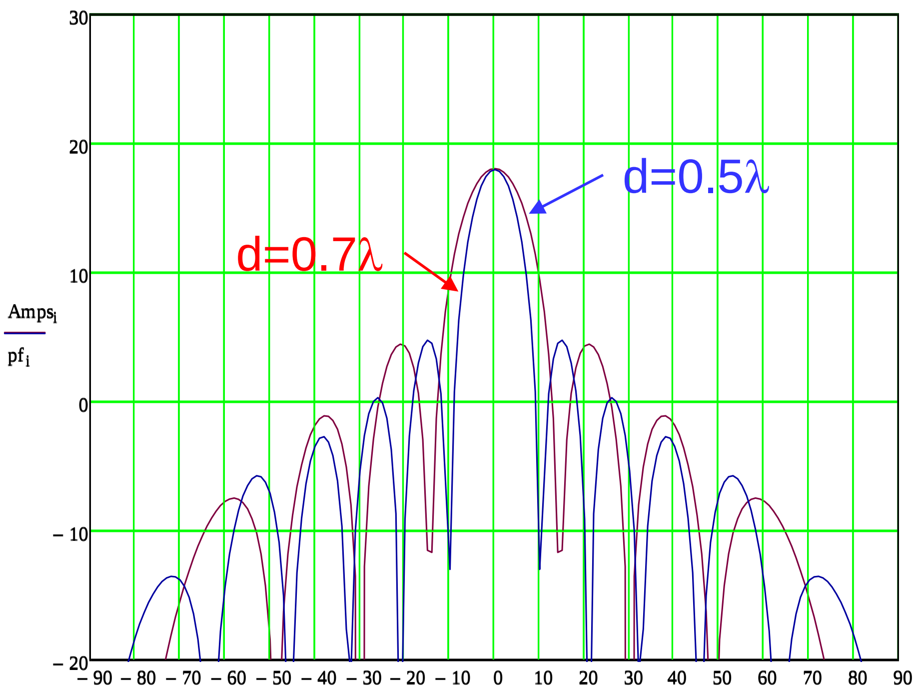
Phased Array Antenna Considerations
- Array Design & Beam Forming Characteristics

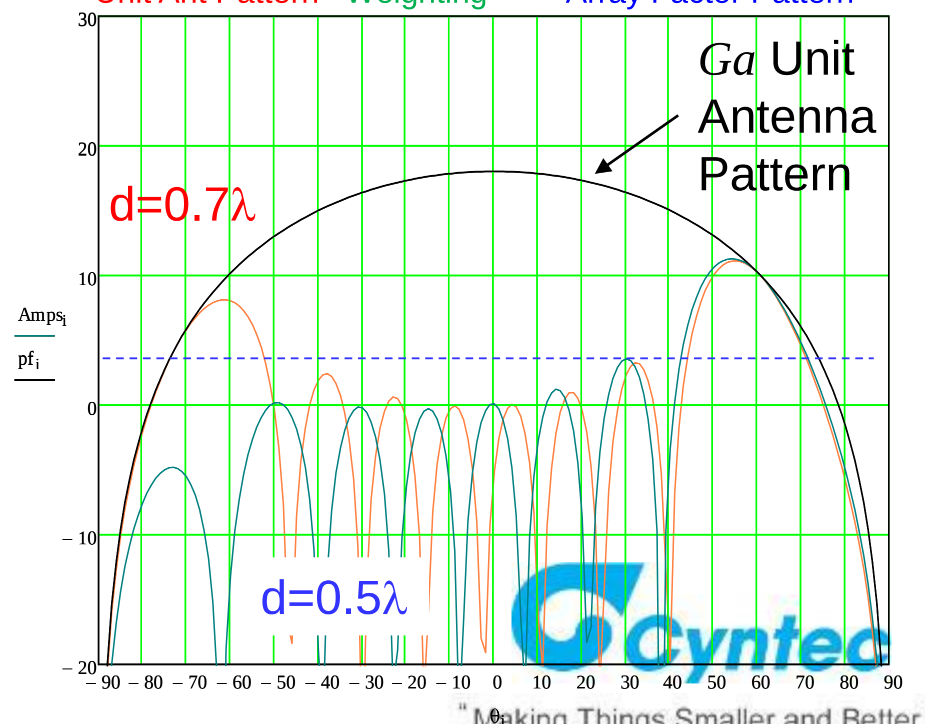
Wider is the Antenna Element Pitch

- ✓ Sharper is the Beam
- × Narrower are the Grating Lobe Pitches
- × Higher is the Side Lobe @ High Steering Angles
- × Narrower is the Sweeping Angle

Array Pattern= $\sum_{n=0}^{N-1} Ga(\theta) \cdot a_n \cdot e^{j\beta_n} \cdot e^{jk_n d\cdot\sin(\theta)}$

Unit Ant Pattern Weighting Array Factor Pattern





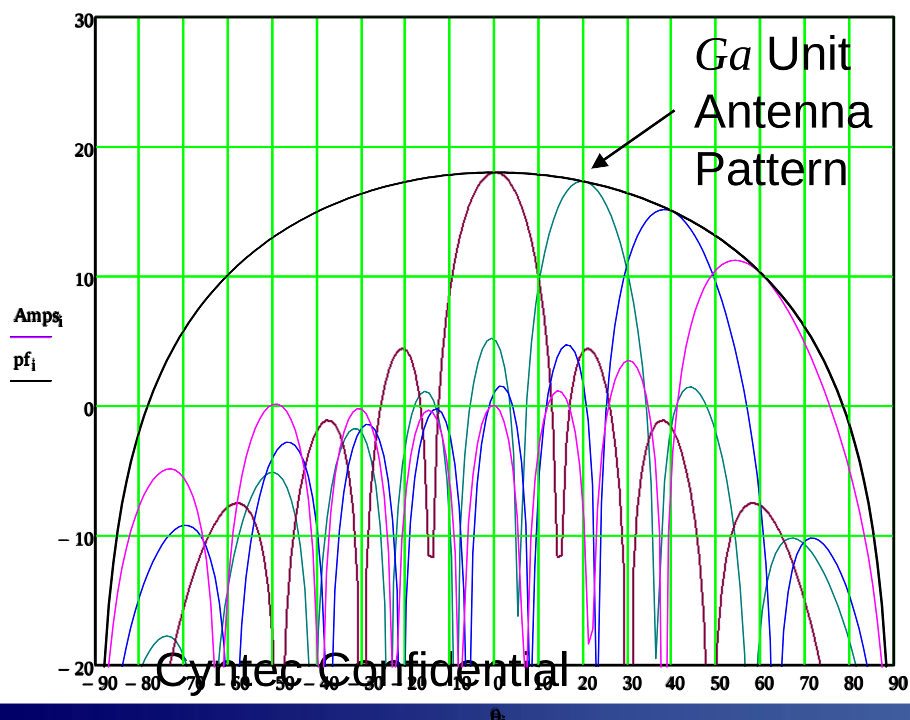
Phased Array Antenna Considerations
- Array Design & Beam Forming Characteristics

- Beam Steering Could be Controlled by The Phase Difference among Each Antenna (β_i)
- Side Lobes of the Radiation Could be Suppressed By Applying Power Weighting of each of the Antenna (a_n)

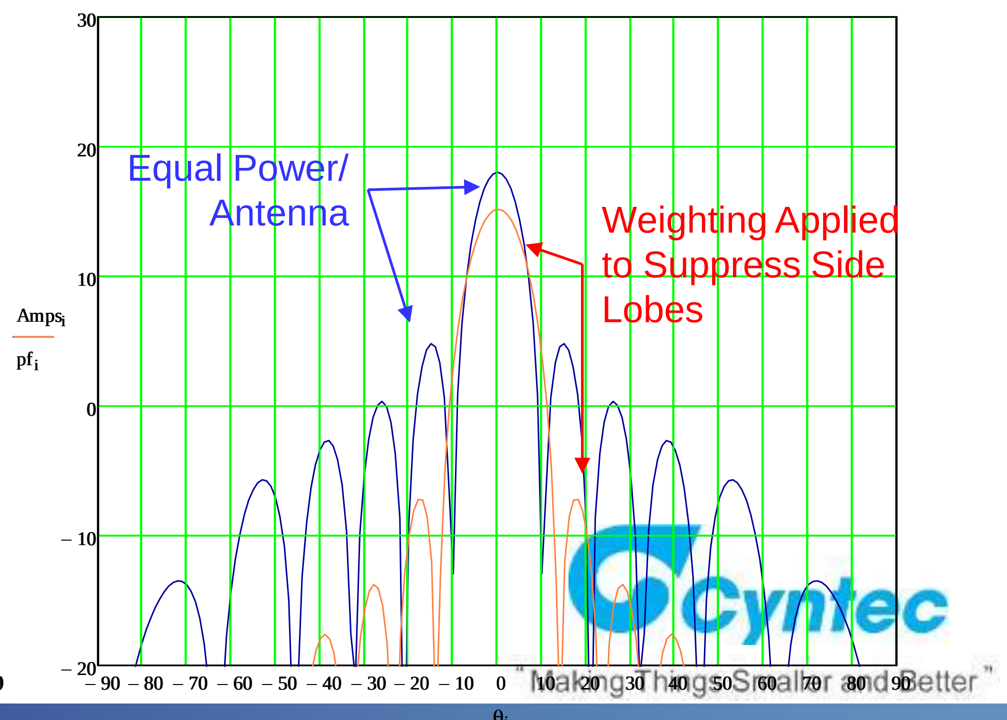
$$\text{Array Pattern} = \sum_{n=0}^{N-1} Ga(\theta) \cdot a_n \cdot e^{j\beta_n} \cdot e^{jk_n d \cdot \sin(\theta)}$$

Unit Ant Pattern　Weighting　Array Factor Pattern

Beam Steering of A Phased Array Antenna



Side Lob Suppression by Applying Weightings

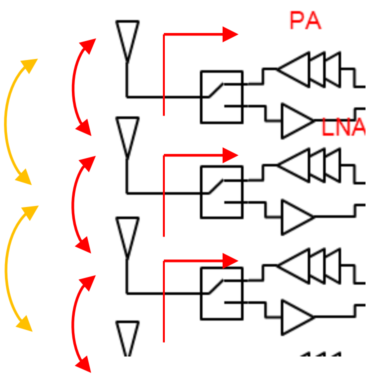


Phased Array Antenna Considerations

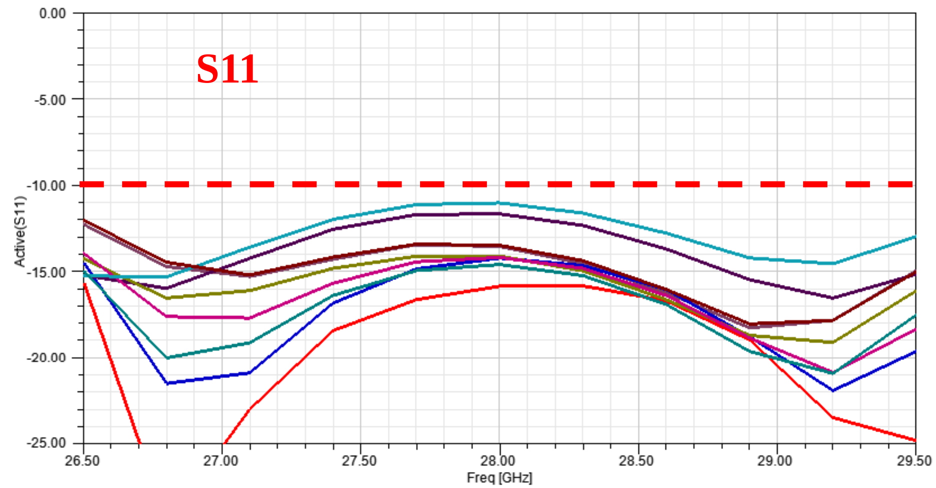
Active S11 Simulation of Antenna Array

Couplings
Amplitude
& Phase

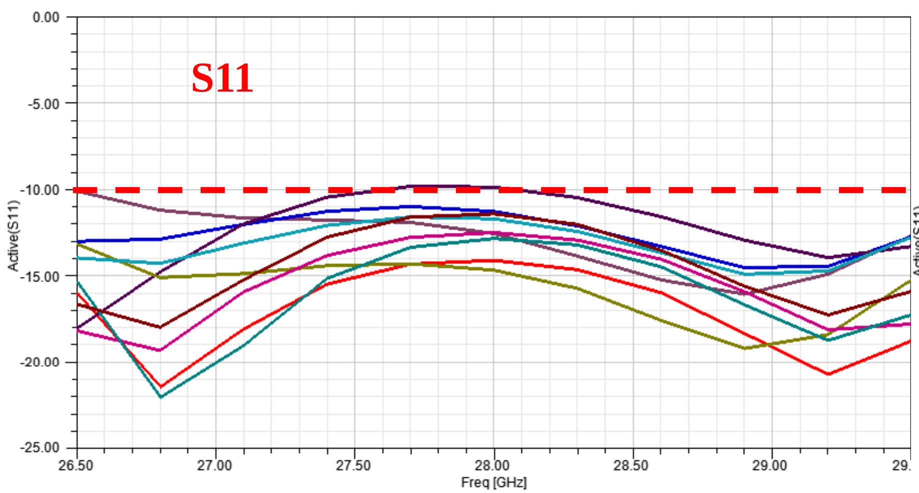
S11i



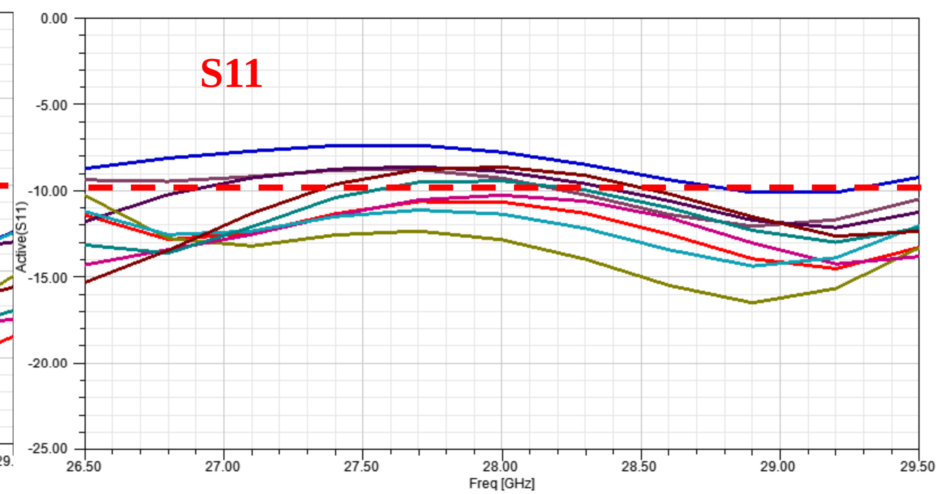
Active S-Parameter : Beam 0°



Active S-Parameter : Beam 20°



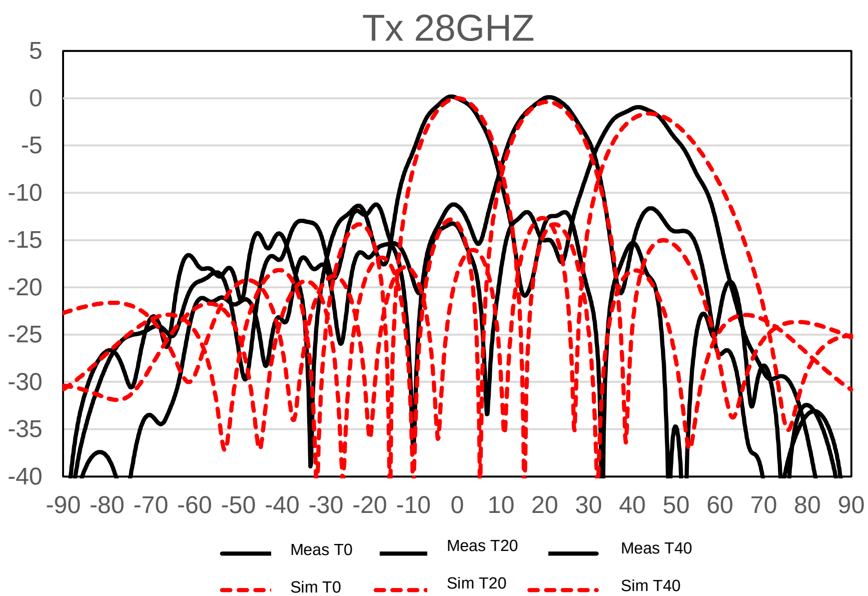
Active S-Parameter : Beam 40°

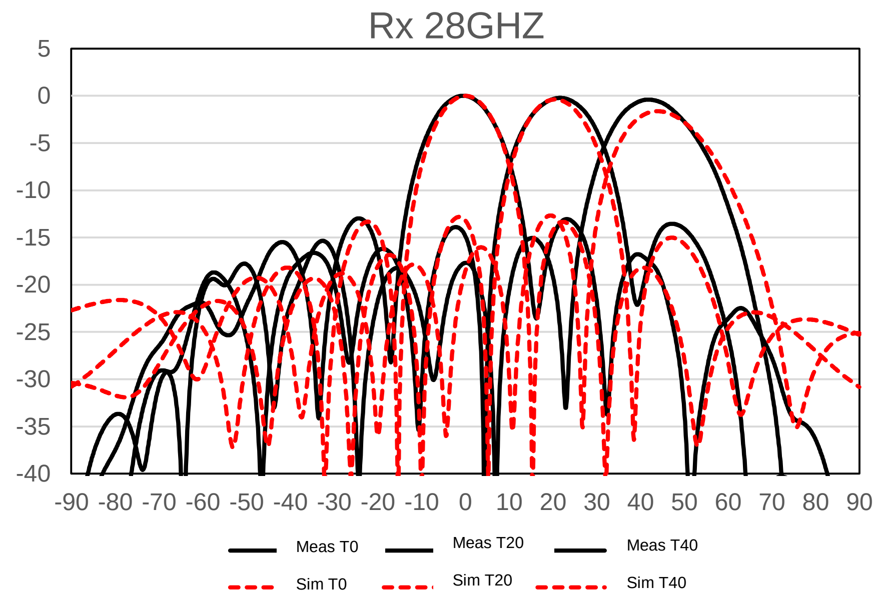


Design Considerations

- Example of 8x8 Antenna Module DALV-RR88-101-B-X

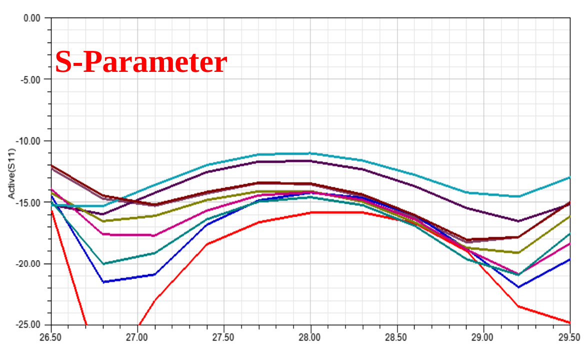
Scan Loss- Measurements vs. Simulations



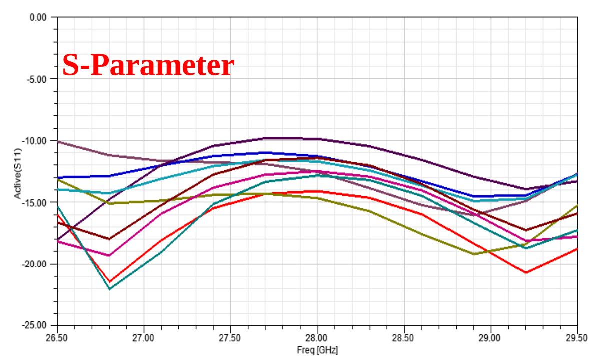


Active S11

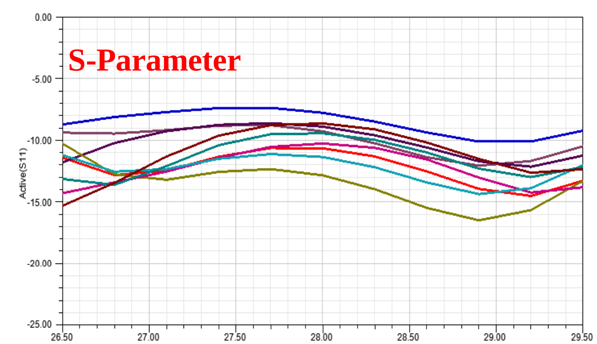
Active S-Parameter : Beam 0°



Active S-Parameter : Beam 20°



Active S-Parameter : Beam 40°



Material Considerations for mmWave Applications

- Low K, Low Loss→ Radiation/ Transmission
- High Resolution→ Integrations
- Arbitrary Layer Structure for Antenna Module → Integrations
- Excellent Material/ Thermal Properties → Overall Performance

	Thin Film on Glass	**Cyntec LTCC/ Photo Image-able**	Low Loss PCB (RO3003)	Note
Dielectric Constant K	3,.8	**3.9 @ 28GHz**	3.0 @10GHz √	Low K with Low Loss Renders Low Absolute Dielectric Loss
Loss Tangent tan δ	~0.0008 @ 3GHz √	**<0.003 @ 28GHz**	~0.001 @10GHz	
Metal Conductivity (Ωm)	1.68 x10^{-8} (Thin Film Cu)	**1.68 x10^{-8} (Electroplated Cu) √ 10^{-7} (Printed Ag)**	1.68 x10^{-8} (Cu Foil) √	Electro-plated Cu metal bears lowest Conduction loss
TCE (ppm/°K)	0.4~0.5 √	**5 (40°~400°)**	XY 16/17 Z 25 (0°~100°)	Low TCE Substrate Yields Calibration Free in Temperature Varying Operation Conditions
Thermal Conductivity (W/m•°K)	3.3 √	**2.5**	0.5	Excellent for Active Antenna Array Thermal Conduction
Process Resolution	+/- 3um with Photo Image-able √	+/5 um @ 25um Line, with +/-0.3% for large Patterns √ **+/- 3um with Photo Image-able** √	+/- 20um	Better Control on Antenna Elements and Array Performance
Multi-Layer Structure	4-Layer Poor Stack	**Yes, Arbitrary Layer Structures**	Yes, Hybrid But Symmetric Stack	SiP Integration Possible for Active Phased Array Module

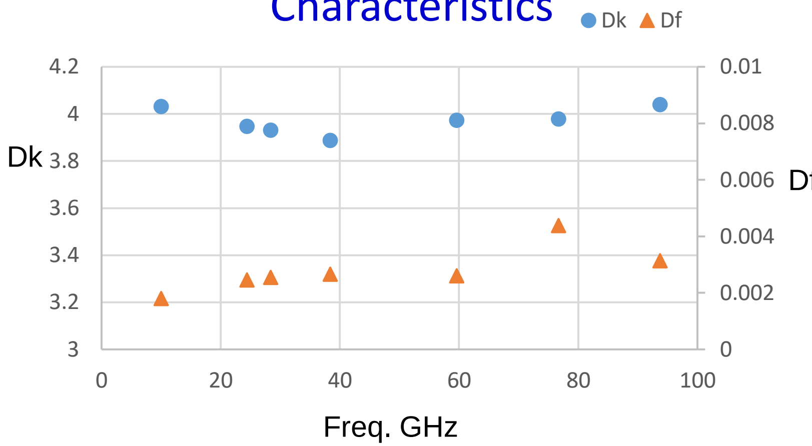
LTCC Platform for mmWave Applications

- Low K (Dk 3.9) Low Loss (Df 0.0023) up to 90GHz
- Excellent Line Loss Among Substrates (0.3dB/cm @ 28GHz)
- Layer Stack Flexibility, Cavity Capability

Cyntec LTCC Performs Lowest Losses

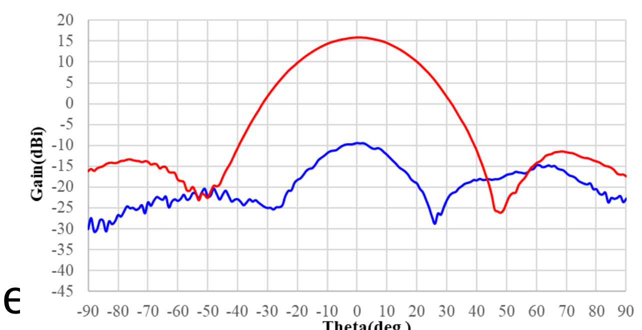
Material	LTCC (K3)	RO3003	ISOLA MT40	RO4350	TU933+
Dk	3.9	3	3.45	3.5	3.2
Df	0.0023	0.001	0.0031	0.0031	0.0034
Cu. Type	Silver	Rolled Cu.	Core	Revese Cu.	Core HVLP
Roughness(Rz)	< 5um	< 5um	< 1.5um	< 8um	< 1.5um
10GHz(dB/cm)	-0.17	-0.18	-0.26	-0.33	-0.429
28GHz(dB/cm)	-0.29	-0.42	-0.45	-0.67	-0.813
Note	Excellent for Process	Hard for Stacking	Symmetric Stack	Symmetric Stack	Symmetric Stack

Cyntec K3 LTCC Electrical Characteristics

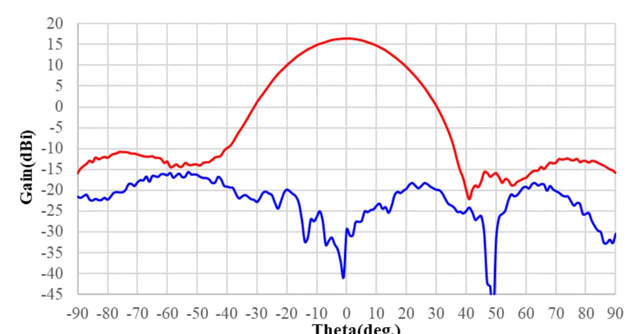


Antenna Radiation Patterns

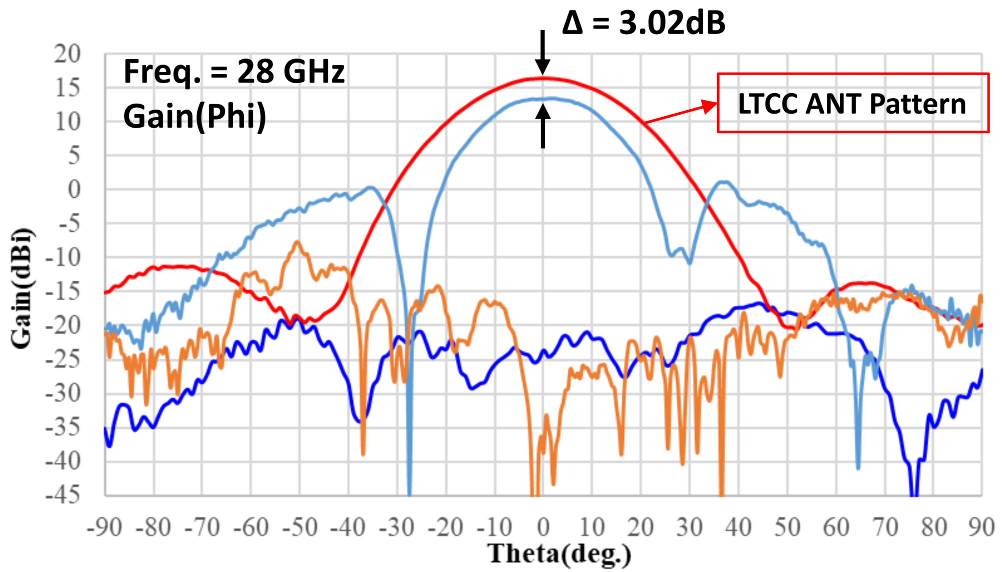
H-Polarization

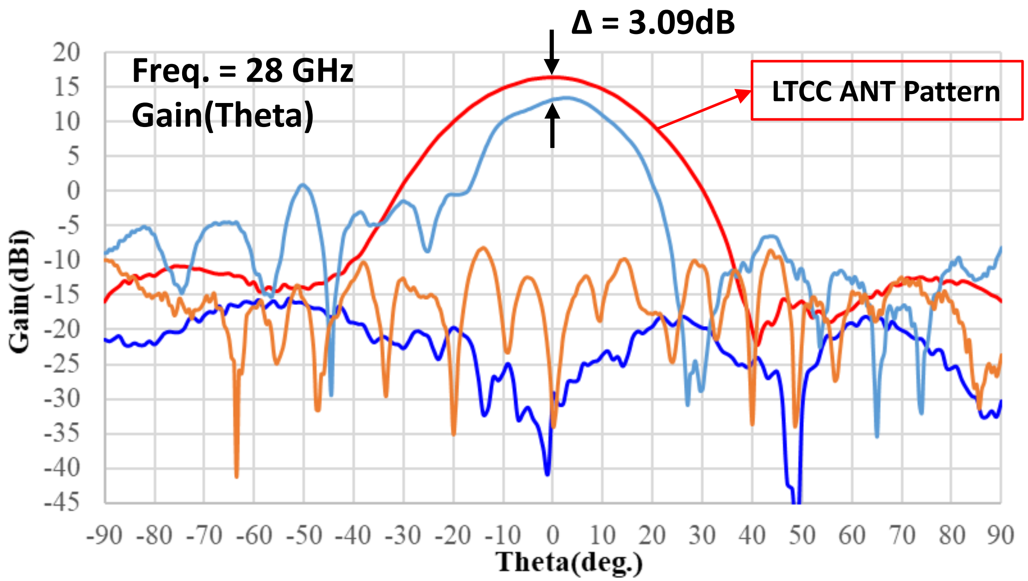


V-Polarization



Benchmark of LTCC and PCB Antenna
- 4x4 Phased Array





LTCC Phased Antenna Performs Higher Gain (>3dB) than that of PCB

LTCC ANT Pattern
- Co-Pol
- Cox-Pol

PCB ANT Pattern
- Co-Pol
- Cox-Pol

"Making Things Smaller and Better"

Cyntec at a Glance

- Power & Communication Components Expert Founded in 1991
- Manufacturer of High Performance & Cost Effective Products
- Profound Bases on Material, Process Platforms & Design/ Verification
- Global Operations with 6 Manufacture Sites in TW & China

Cyntec for 5G mmWave Antenna Module

- Roadmap - Profile Covering High/Low Power Types
- In-house Substrate & Packaging Platform for Antenna Module Applications
- Innovative Calibration Technique for Phased Array Antenna Design & Verification
- RF Module Manufacturing Experience

Cyntec

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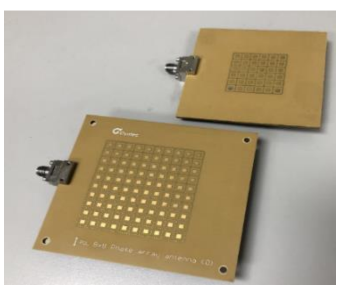
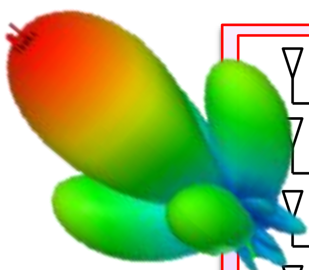
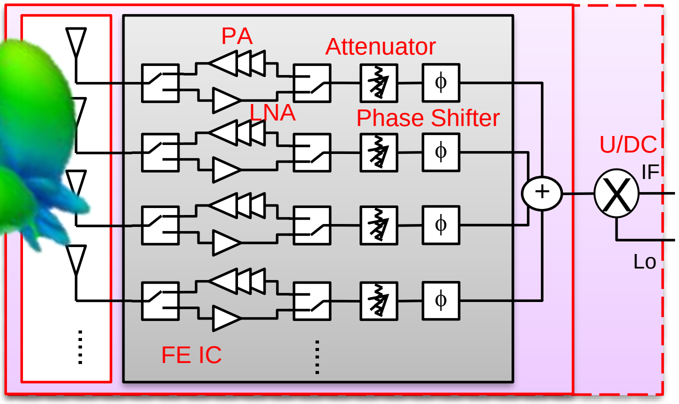
Cyntec mmWave Antennas for 5G Applications

- From Passive Antenna Units, Array to Active Array Modules
- In House Tech Platforms: Organic Multi-Layer & LTCC

Small Cell Modules	CPE Module	Smart Phone AIP
Power/ Sensitivity		Miniaturization Size/ Performance







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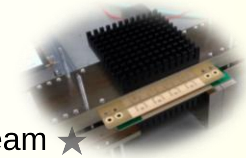
Roadmap - Profile Covering High/ Low Power Types

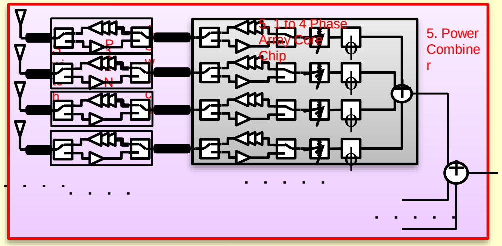
High Power Types

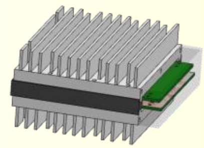
2x4 28GHz Tx Module ★
ADI GaAs EIRP ~46dBm



8x8 39GHz 4 Stream ★
High Power Module (GaN) 2020Q3

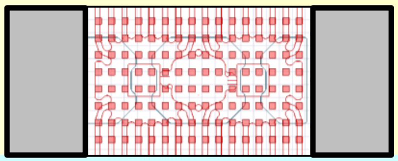
2x4 28GHz Module ★
GaN EIRP ~50dBm





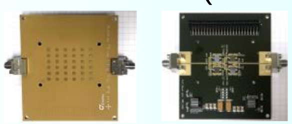
2x4 28GHz Module ★
GaAs EIRP ~50dBm

★ 8x8 28GHz Module
GaN EIRP ~62dBm

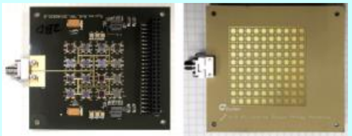


Medium/ Low Power Types

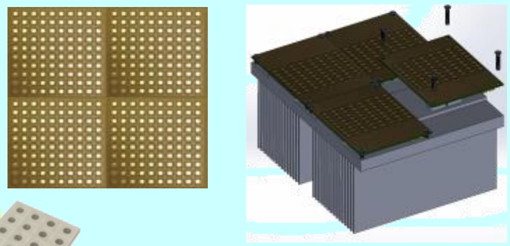
★ 4x4 28GHz Dual pol Antenna (H/V) Module
DADV-RR44-B (CMOS) 2019Q4



★ 8x8 28GHz 45 Deg pol Antenna
Module (CMOS) 2020Q2



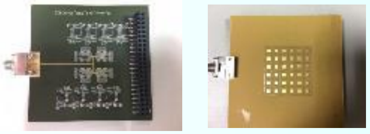
★ 16x16xN 28GHz Dual pol Antenna
Module (CMOS) 2020Q4~2021Q2
(Scaled up by 8x8 AIP)



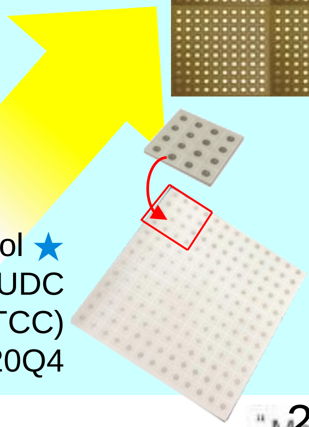
★ 8x8 28GHz Antenna Module
DALV-RR88-B (CMOS) 2019Q4

8x8 28GHz Dual pol ★
Antenna AIP (CMOS)
DADI-RR88-B 2020Q4

★ 4x4 28GHz Antenna Module (CMOS)
DALV-RR44-B 2019Q3



8x8 28GHz Dual pol ★
Antenna AIP w. UDC
(CMOS+LTCC)
DADI-RI88-B 2020Q4



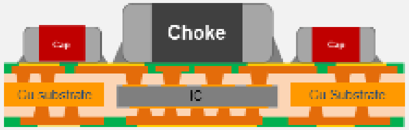
2019 2020 2021

Process Platforms
- Packaging Process Platforms for Antenna Module Applications

Substrate
- Low K, Low Loss LTCC Substrate & Packaging
- Asymmetric Organic Substrate Process

SiP Package
- Organic Substrate and Under Fill molding(MUF)
- Conformal Shielding, EMI Shielding
- High Density SMT

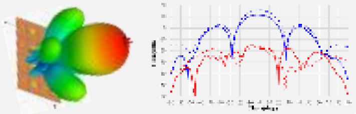
Embedded Package
- 3D high density package for size reduction
- Low inductance (high frequency)
- Double side heat transfer
- Better reliability



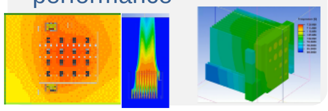
Package Platform

Optimization for Products

Performance
- EM Simulation
- Antenna Design
- RF Component Design
- Module Integration Design

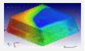


Thermal
- ANSYS Icepak
- Rth(jc) measurement
- Structural design for optimizing thermal performance



Stress/Material
- ANSYS Stress Simulation
- Interface adhesion & Material Evaluation
- Design for stringent reliability

Mold Flow
Mold Flow Simulation: Moldex3D

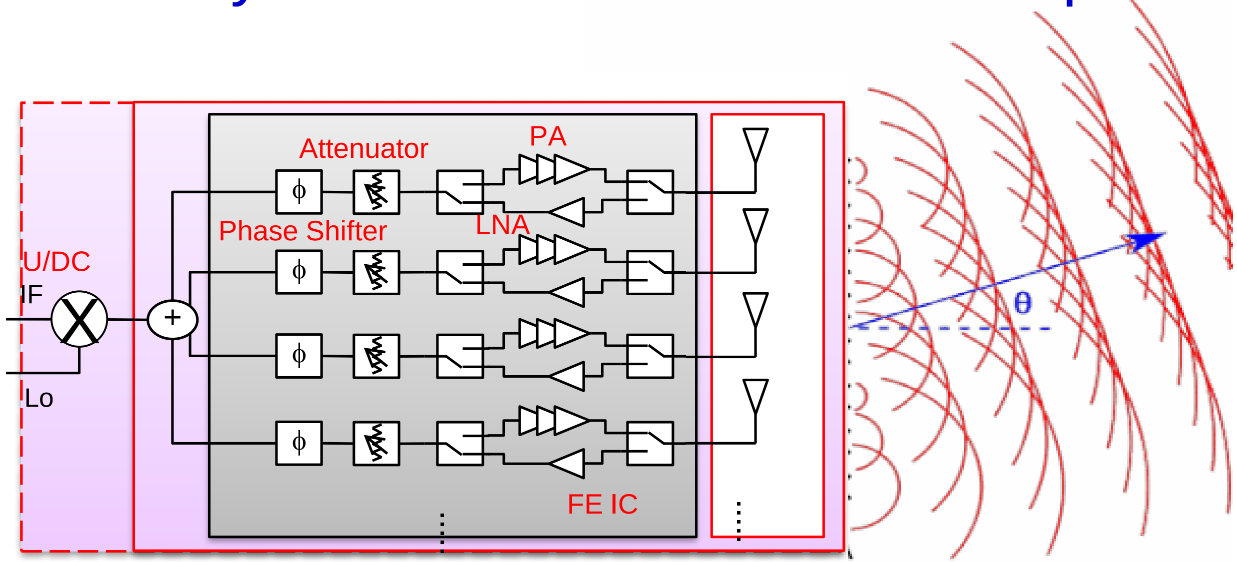


- Filling simulation
- Wire sweep and wire sagged simulation
- Paddle shift and warpage
- Seam and void prediction

Process
- LF/ABF Adhesion
- Laser drilling (Via Desmear Improving)
- ABF/BUF Roughen (Interface Adhesion Improving)

Design/Simulation/Material Optimize

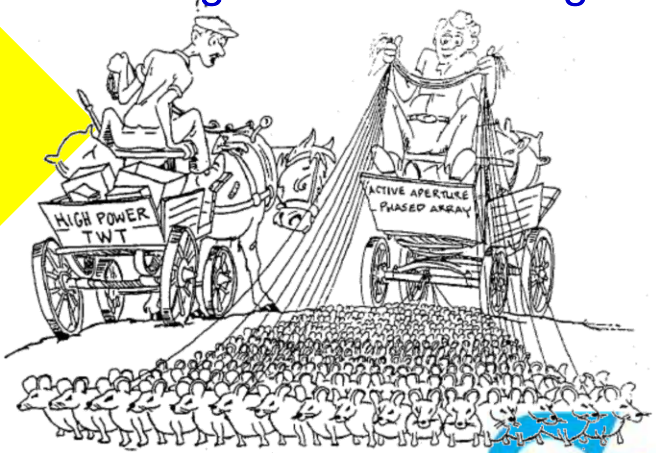
Phased Array Antenna Calibration Techniques



Before Calibration
Non-Aligned, Disordered

Calibration

Post Calibration, Aligned with Strengths & to The Target



C. Fowler "Old Radar Types Never Die; They Just Phased Array' or 55 Years of Trying to Avoid Mechanical Scan" IEEE AES Systems Magazine, September

Innovative Calibration Technique Greatly Saves Beam Table Generation Time

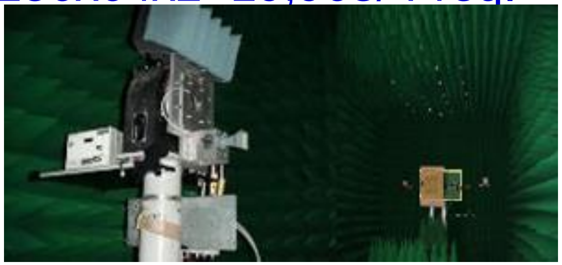
Innovative All Channel on Calibrative Method

- Far Field Measurement Method
- ✓ Channel Coupling Effect Considered
- ✓ Quick Generation for Beam Table Calibration (10+ Times Quicker)

Traditional Calibration Method

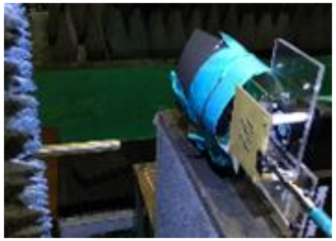
- Near Field Measurement Method
- \- Single Channel Phase Gain, Neglecting Coupling Effect
- \- Time Consuming due to State by State, Channel by Channel Measurement

Measurement Points Required 156x64x2=19,968/ Freq.

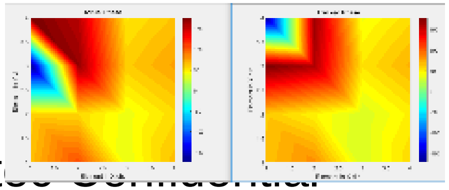


Steering Beam Generation
+/- 60˚ AZ/ EL 156 Beams
64 Antenna, 64bit Phase/ 32 Bit Gain Control

Measurement Points Required 64x32x2x64=262,144/ Freq

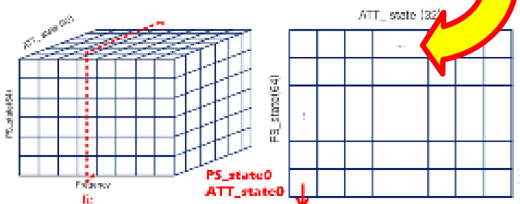


Eigen Vectors for Beams



Beam Tables

Optimized Phase/ Gain State Matrix



Beam Forming Calculations

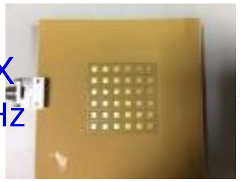
28GHz Phased Array Antenna Module Prototypes
- Wide Bandwidth Covering N257/ N261 Bands

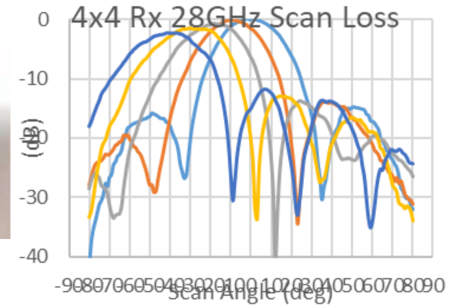
Operation Frequency Bands: 26.5~29.5GHz
Conform to 5G Antenna Requirement

Measured Scan Loss

4x4 Vertical Polarization Module DALV-RR44-101-B-X

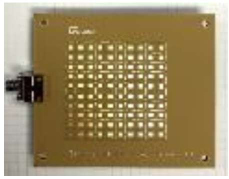
- Tx: EIRP 43 dBmi @P1dB; 32dBmi @3% 64QAM 100MHz BW)
- Rx: Gain 36dBi, EIS -63dBm (@3% 64QAM 100MHz BW)
- Beam Steering H/E Cut +/- 40˚

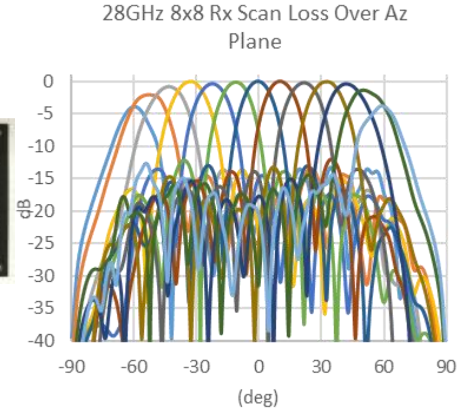




8x8 Vertical Polarization Module DALV-RR88-101-B-X

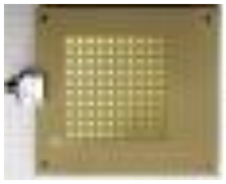
- Tx: EIRP 54.5 dBmi @P1dB; 47dBmi @3% EVM 64QAM 100MHz
- Rx Gain: 39dBi, EIS -68dBm (@ EVM 3% 64QAM BW:100MHz)
- Beam Steering H Cut +/- 60˚, E Cut +/- 45˚

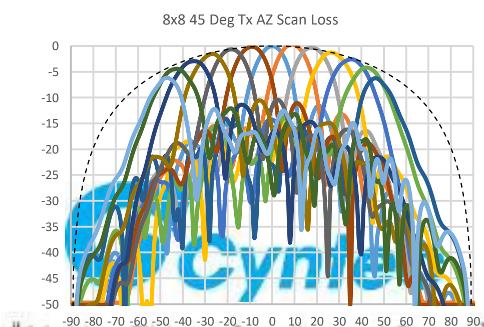




8x8 45 Deg Polarization Module DALI-RR88-101-B-X

- Tx: EIRP 54.5 dBmi @P1dB; 47dBmi @3% EVM 64QAM 100MHz
- Rx Gain: 39dBi, EIS -68dBm (@ EVM 3% 64QAM BW:100MHz)
- **Beam Steering H & E Cut +/- 60˚**





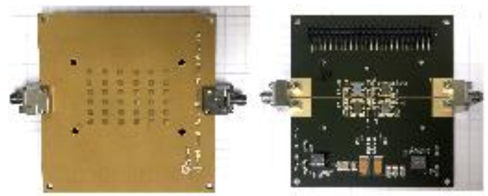
28GHz Phased Array Antenna Module Prototypes
- Wide Bandwidth Covering N257/ N261 Bands

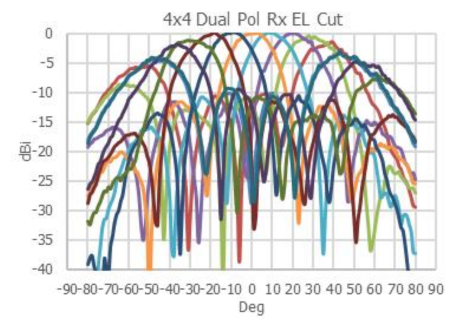
Operation Frequency Bands: 26.5~29.5GHz
Conform to 5G Antenna Requirement

Measured Scan Loss

4x4 Dual Polarization Module DADV-RR44-101-B-X

- Vertical/ Horizontal Polarization
- Tx/ Pol: EIRP 45 dBmi @P1dB; 35dBmi @3% EVM 64QAM 100MHz
- Rx/ Pol: Gain 36dBi, EIS -63dBm (@ EVM 3% 64QAM BW:100MHz)
- Beam Steering H/E Cut +/- 40˚ H/ V Pol

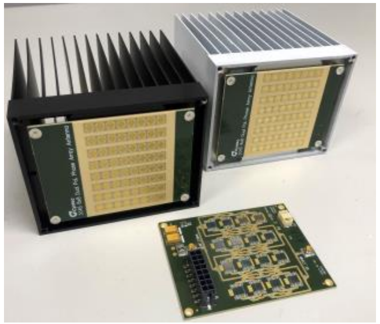




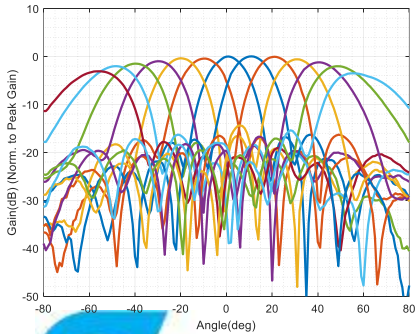
Now Available!

Scalalable 8x8 +/-45 Deg Dual Polarized Antenna Integrated Package DADI-RR88-101-B-X

- +/-45 Deg Polarization
- Tx/ Pol: EIRP 55 dBmi @P1dB; 47 dBmi @3% EVM 64QAM 100MHz
- Rx/ Pol: Gain 39dBi, EIS -69dBm (@ EVM 3% 64QAM BW:100MHz)
- Beam Steering AZ +/- 60˚, EL +/-20˚



8X8 45 Dual Pol Tx AZ Cut



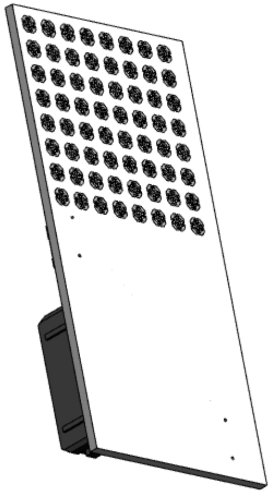
Cyntec
"Making Things Smaller and Better"

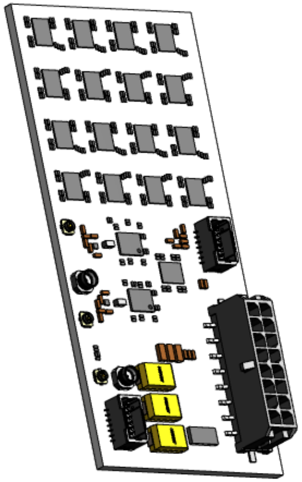
LTCC Based Antenna Integrated Package
- DADI-RI88-101-C-X

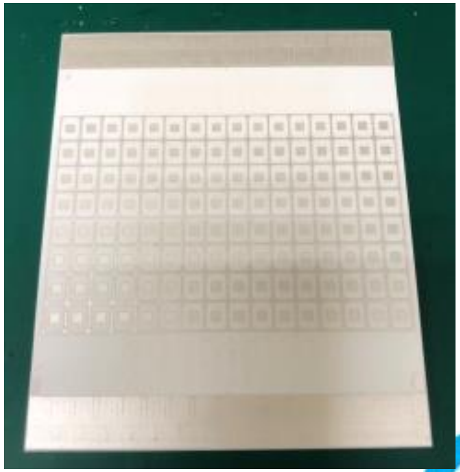
Scalable for Small Cell & Base Station Applications

- Frequency
  - RF 26.5~29.5GHz (N257)
  - IF: 2.6GHz~5.8GHz
  - Lo: 5.4~6.6GHz
- +/-45 Deg Polarization
- **Beam Steering AZ +/- 60˚, EL +/-60˚**

New
2020Q1

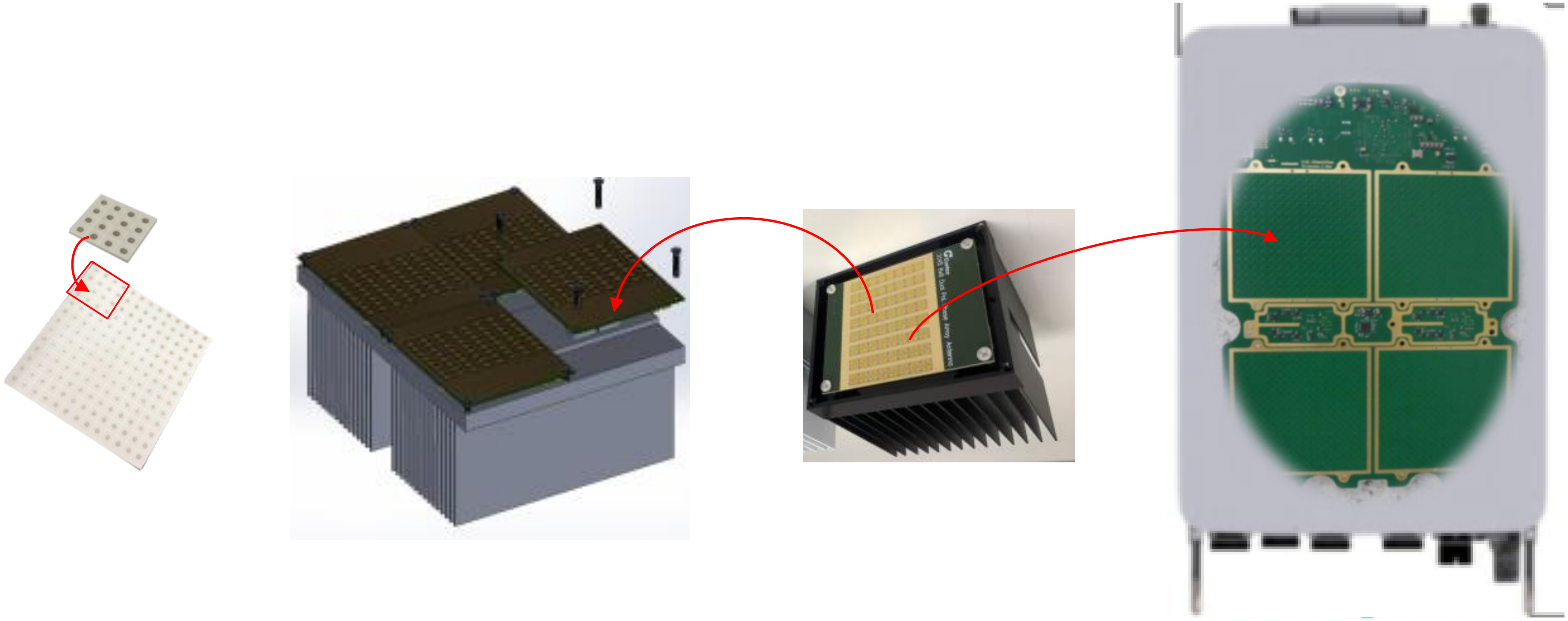






28GHz Phased Array Antenna Module Prototypes
- Scale up to Large Array with 8x8 Base Unit Array (Under Development)

- Base Unit Array: 8x8 Dual Polarized AIP
- Scale up Topologies: 8x8xN, 16x16xN
- Scale up Integration with Re-configurable Firmware Control



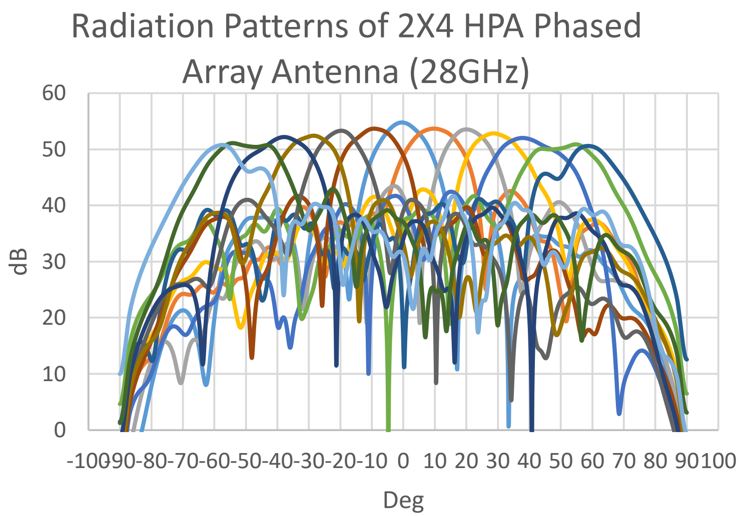
Phased Array Antenna Module Prototypes
- 28GHz High Power Antenna Module Prototype

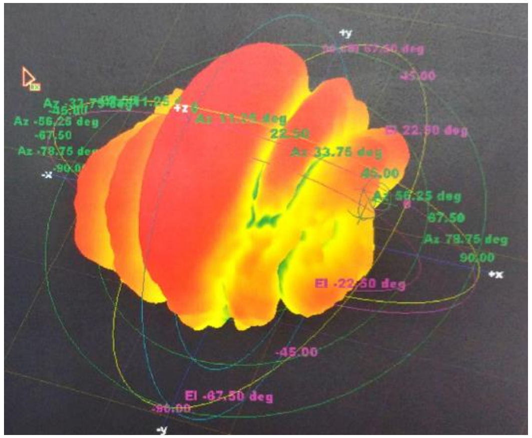
Features

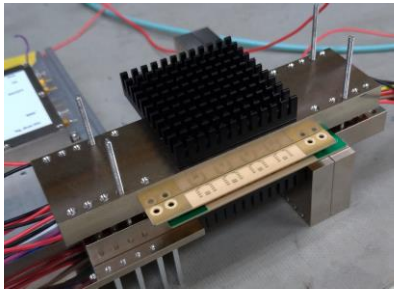
- High Power Miniaturized Architecture
- GaAs PAM Integrated
- Steering Angle: Fan Beam, +/-60 deg AZ.
- Array Type: 2x4
- EIRP @1dB: 46.5dBmi
- Gain: 54dB
- Power Consumption:14W

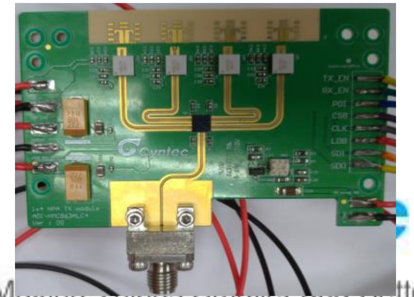
12.5% Power Saving Comparing to CMOS Type w. Equivalent EIRP

	HPA 2x4 Array	CMOS 4x4x2 Array
Active Antenna Gain(dBi)	54	40
EIRP(dBmi) @P1dB	47.05	46
Power Consumption(W)	14	16







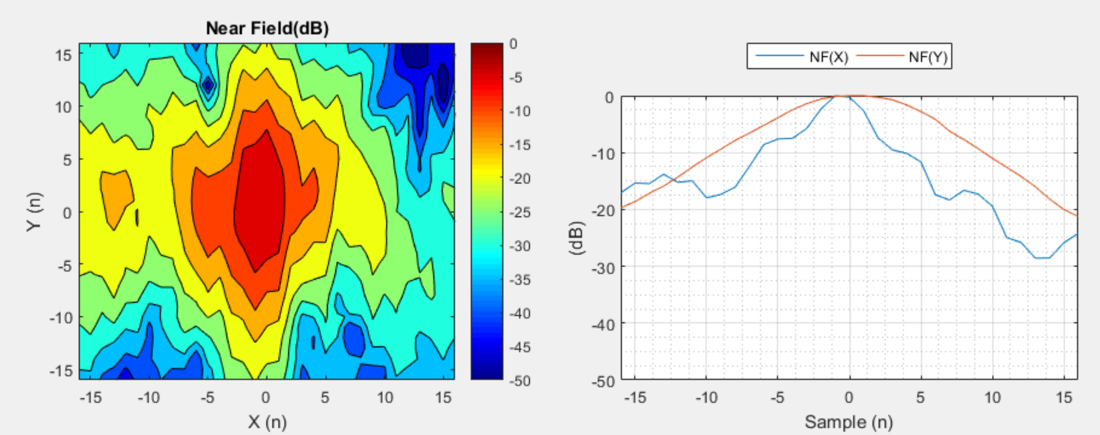


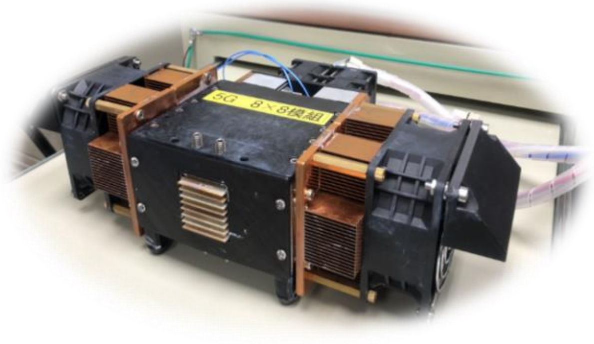
High Power Device Challenges for Phased Array Antenna

- 39GHz 2x8 High Power Array Antenna Module Prototype

- 16-Element/ Beam, 4 Beams
- Output Power per element: 29.67dBm
- EIRP: 53.67dBm (Linear Power)

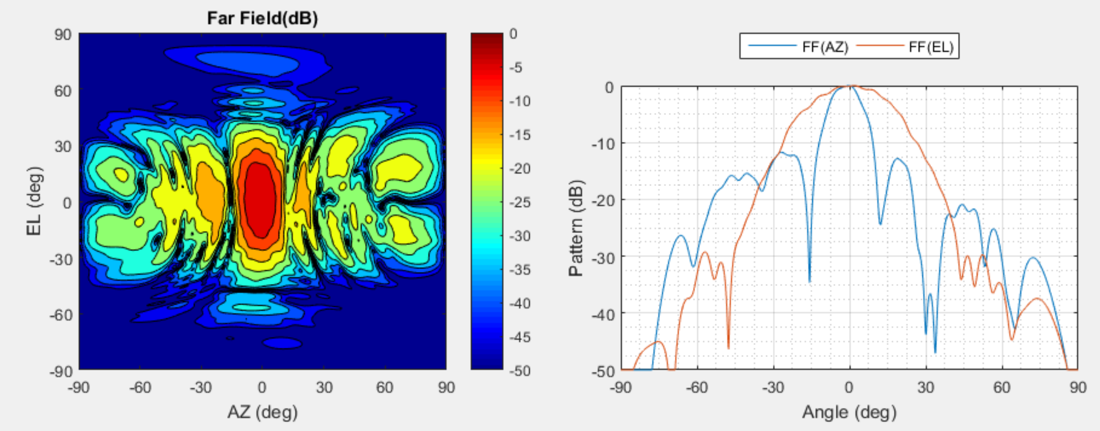
Near Field Measurement Data

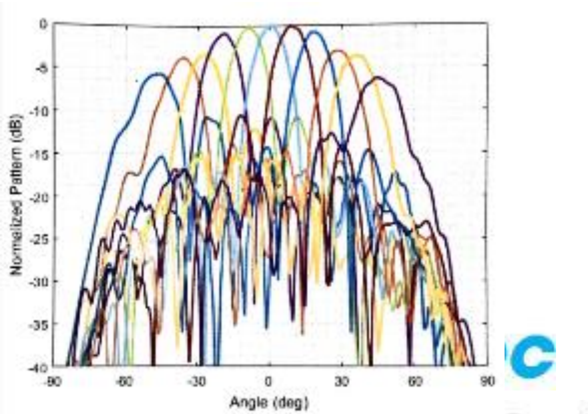




	Value
Input Power	0dBm
Element	N=16
Element antenna Gain	Ge=0
Output Power per element	29.67dBm
EIRP	53.67dBm

Far Field Beam Pattern





Conclusions

- 5G mmWave Antenna Modules Covering Base Station, Small Cell & Base Station Applictions are developed
  - Series of CMOS Based 4x4, 8x8 Single Pol & Dual Pol Phased Array Antenna Modules are Developed and Verified
  - GaAs & GaN Based HPA Type Antenna Modules are under Development
- Cyntec Team Owns Capabilities & Experiences on mmWave Phased Array Antenna Module Development, Design, Calibrations, Verifications, & Manufacture
- Cyntec is Ready to Serve you toward Reliazations of 5G mmWave Applications